



# Dust Storm Impacts

## on Human Mars Mission Equipment and Operations



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# Mars Isn't Your Daddy's Surface Exploration Mission

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- ❑ **Apollo spacecraft were one-time use, each landing at a different site**
  - NASA is looking at multiple missions to a single landing site
- ❑ **Apollo missions were about a week long**
  - Mars mission will start *at least* two years before the crew even launches from Earth, when cargo is pre-deployed to Mars
  - Mars surface equipment life may be 10+ years of active use
- ❑ **Apollo crews only ventured a few km from Lander**
  - NASA is looking at Mars surface scenarios where crews may take “camping trips” hundreds of kilometers from a landing site
- ❑ **Apollo didn't worry about forward contamination**
  - If we're searching for life on Mars, we have to be more careful





# Surface Mission By the Numbers

*No firm decisions have been made  
But this is the current thinking*

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## Multiple visits to a single landing site

Economics are better if we re-use assets, rather than abandon them

**100 km**

### Notional crew excursion radius from landing zone

- Goal is to extend as far as possible
- Robotic assets may rove even further

**~500**

### Days maximum surface stay for any given mission

- Driven by orbital mechanics
- Short (<30 day) stays have been considered, but don't save \$

**Twenty Six**

**Months between mission opportunities**

Conjunction class missions



### Number of crew to the surface for any given mission

Studies have assessed 2 to 6 crew per mission



# Here's What a Mars Campaign *Might* Look Like

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**FIRST** we send cargo, including a surface power system



Power System +  
Cargo

**THEN** we send an Ascent Vehicle and ISRU to fill its empty tanks



Ascent Vehicle +  
Propellant  
Manufacturing System

**WHEN** the tanks are full, crew lands and begins surface mission



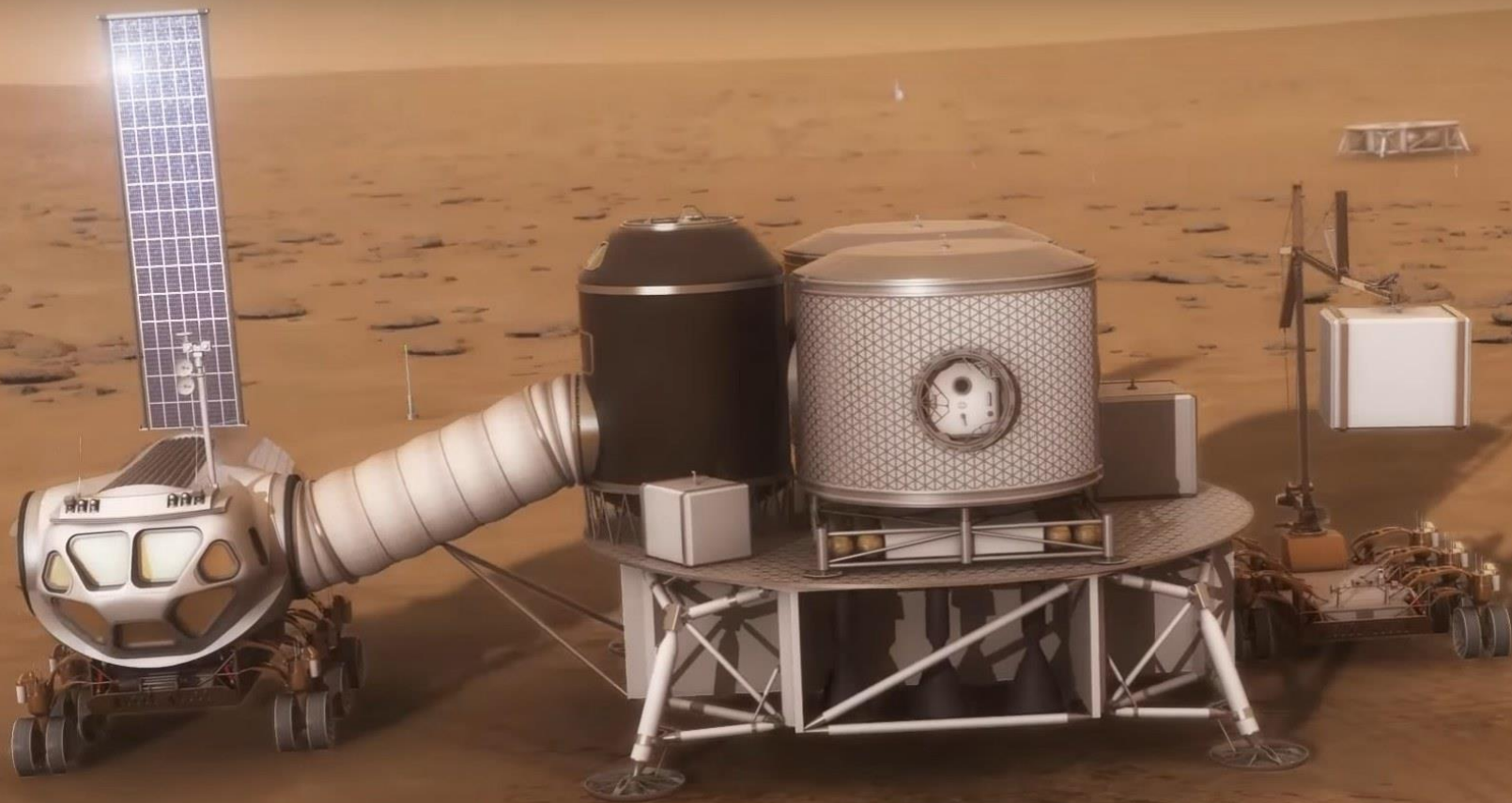
Habitat + Crew  
+ Logistics

**SUBSEQUENT** crews land at the same site and use existing infrastructure



Additional Crew  
+ Ascent  
Vehicles + Cargo





# Impacts to Equipment

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# Surface Habitat

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❑ Habitat is re-used for multiple long-duration expeditions

❑ Considerations

- Crew ingress/egress: open hatch alternative, dust-resistant pressure seals, locking mechanisms
- Cabin fans/filters to remove airborne dust in the cabin and portable vacuum cleaners to clear surface dust (+ power for both)
- Regenerative air/water system compatibility with chemicals in dust
- Ability to remove embedded dust from softoods
- Cleaning tools
- Clothing and cleaning rags: dispose or wash?
- Dust accumulation on windows, handrails, radiator panels

❑ In spite of best efforts, some dust is likely to migrate into the habitat







# Surface Power Systems

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- ❑ Solar Power is sensitive to accumulated *and* atmospheric dust
  - Robots can go dormant, but humans can't
- ❑ We can clean dusty solar arrays—but can't fix atmospheric dust
  - Over-size arrays and increase energy storage capacity to survive storm
  - Or develop alternatives, such as fission power
- ❑ Power cable connections between surface assets will be challenging
  - Need dust-resistant connectors
  - Some of these connections may be made by robots before the crew arrive





# Robots Can Hibernate When Power Is Low

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**But humans have to breathe, eat, stay warm and get back home**

Spirit Selfie on Sol 586

*Image courtesy of  
Cornell University*



*Image courtesy of NASA/  
JPL-Caltech/Cornell*



**Dust Accumulation on Spirit's solar arrays reduced available power**



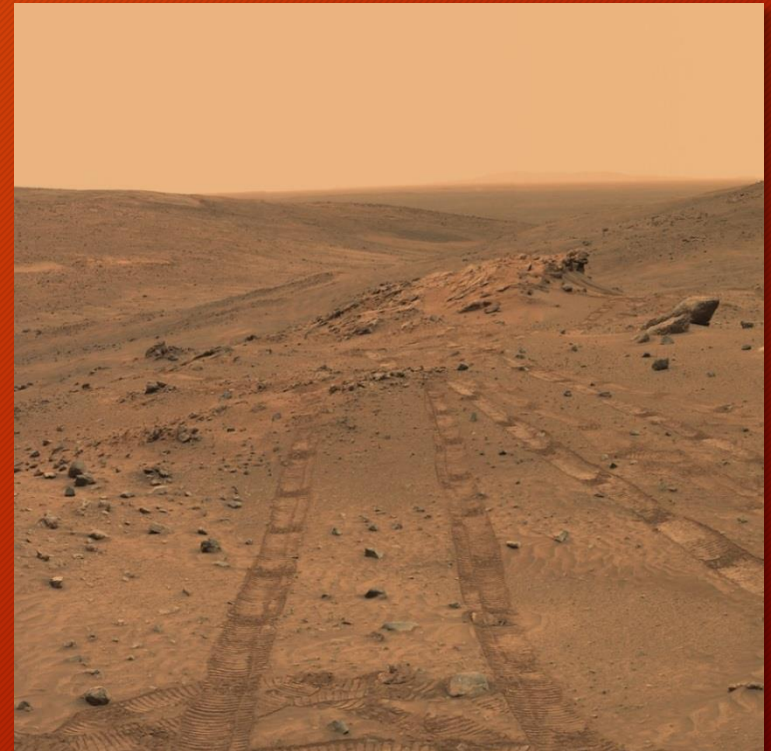


# Rovers

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## ❑ Pressurized Crew Rovers are Mobile Habitats

- All the same concerns as a stationary habitat
- Accumulation can compromise even non-solar rovers (Apollo battery)
- Navigation optics
- Worst-case: solar-powered rover caught in lengthy, severe storm away from the habitat





# EVA Spacesuits and Tools

**EVA**  
Extravehicular  
Activity

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- ❑ **Biggest concern: How/where to perform routine maintenance on dusty spacesuits?**
- ❑ **Considerations:**
  - Crew ingress/egress dust mitigation
  - Seal and mechanism integrity
  - Managing dust accumulation on helmet visor, backpack, boots, gloves, thermal components
  - Abrasion damage to seals, visors, cameras
  - Dust embedded in softgoods, such as suit fabrics
  - EVA Tools: overheating, grit abrasion of mechanisms
- ❑ **May need to leave EVA suits on Mars unless cleaned to meet planetary protection guidelines**
  - Cost penalty to bring new suits with new crews
  - Alternative is to refurbish/resize old suits on Mars for new crews



*Apollo 17  
Dusty EVA suit & Astronaut Cernan*



*Notional Mars EVA Suit Soiling*





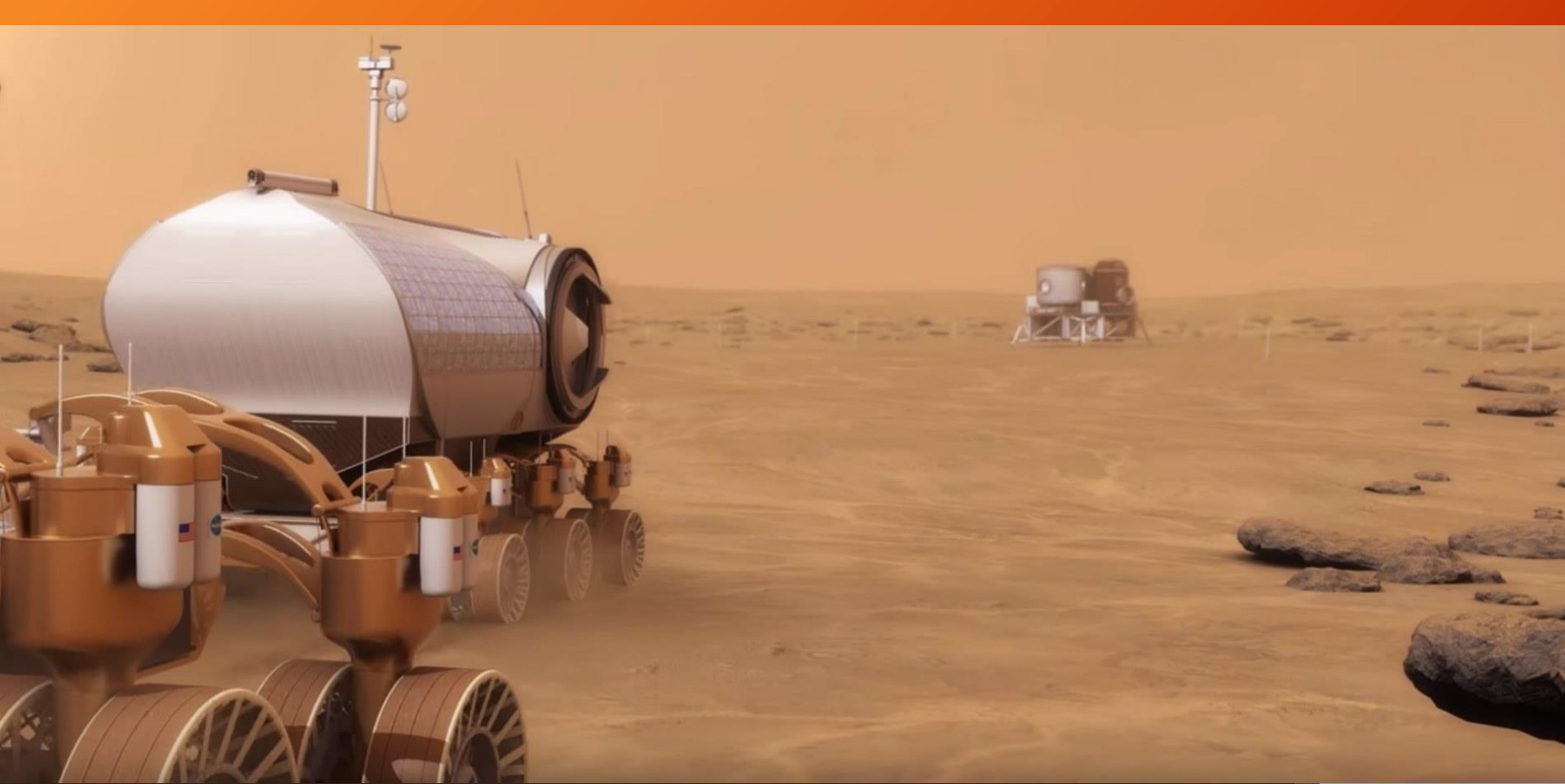
# Mars Ascent Vehicle

**MAV**  
Mars Ascent  
Vehicle

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- ❑ MAV is the first leg of the crew's return to Earth
- ❑ Similar concerns as habitat
  - Airborne dust in the cabin, grit abrasion on seals and mechanisms, reduced window visibility or thermal system malfunction due to dust accumulation
- ❑ MAV is a key link in the planetary protection chain
  - If we can keep dust out of the MAV, we can keep Martian dust from migrating back to Earth
- ❑ Key to minimizing dust in MAV is to never expose cabin to Mars
  - One option is tunnel from a rover to the MAV





# Impacts to Operations

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# Landing on Mars

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- ❑ Storms along well-worn tracks may influence landing site selection
- ❑ Landing during a dust storm could make it difficult to detect and avoid hazards
  - Boulders, sand dunes, rovers, surface habitat
  - Mitigation might include advanced hazard detection and avoidance systems
- ❑ Lengthy storm could cut into schedule margins for critical surface operations, such as manufacturing propellant from Mars resources for crew departure
- ❑ Equipment sensitive to dust accumulation is equally affected by man-made dust storms produced by lander descent engines

*Click below to play on-line video*

# Descent Engines Will Kick Up Dust

Morpheus Free Flight #10, NASA Kennedy Space Center

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*Jump  
to 2:15*

Engine dust plumes will have the added complication of unburned propellants or propellant byproducts mixed with the dust





# Habitat Operations

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- ☐ **Keeping dust out of the habitat is likely to involve special operational procedures**
  - May add time getting EVA crew back inside
  - Concern for emergency ingress
- ☐ **Housekeeping is likely to be time-consuming on Mars**
  - How will we clean the cleaning tools?
  - How much consumables mass will be devoted to cleaning, and will this mass have to be delivered from Earth?
- ☐ **Reduced visibility through habitat windows could disrupt telerobotic operations or science activities**



# Rover Excursions

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- ❑ **Reduced driving visibility and solar power availability could influence surface exploration planning**
  - Poor visibility makes driving treacherous
  - Crew rescue schemes, remote safe havens, better storm prediction, or surface navigation and hazard avoidance provisions
- ❑ **Special operational procedures could add time getting EVA crew back into the rover**
- ❑ **Housekeeping will be time-consuming**
- ❑ **Will need time and consumables to repair grit-damaged pressure seals and mechanisms**





# EVA Operations

EVA

Extravehicular  
Activity

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- ❑ Clearing dust off of solar/radiator panels, windows, etc. could be time-consuming
  - Cuts into science operations time
- ❑ Ideally, equipment will be designed to shed dust, or will include autonomous dust clearing provisions
- ❑ Getting crew in/out of dusty suits may add time
  - Cuts into overall EVA time





# MAV Ascent

MAV

Mars Ascent  
Vehicle

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- ❑ Like the lander's descent engines, the MAV's ascent engines will create a man-made dust storm
  - Lofted dust—potentially mixed with ascent propellants or residues
  - Settling on the habitat or rovers
- ❑ Ascent flight paths that avoid surface infrastructure overflight will be desirable
- ❑ Haven't identified any reason MAV can't launch in a dust storm
  - Visibility may make pre-launch preparations difficult



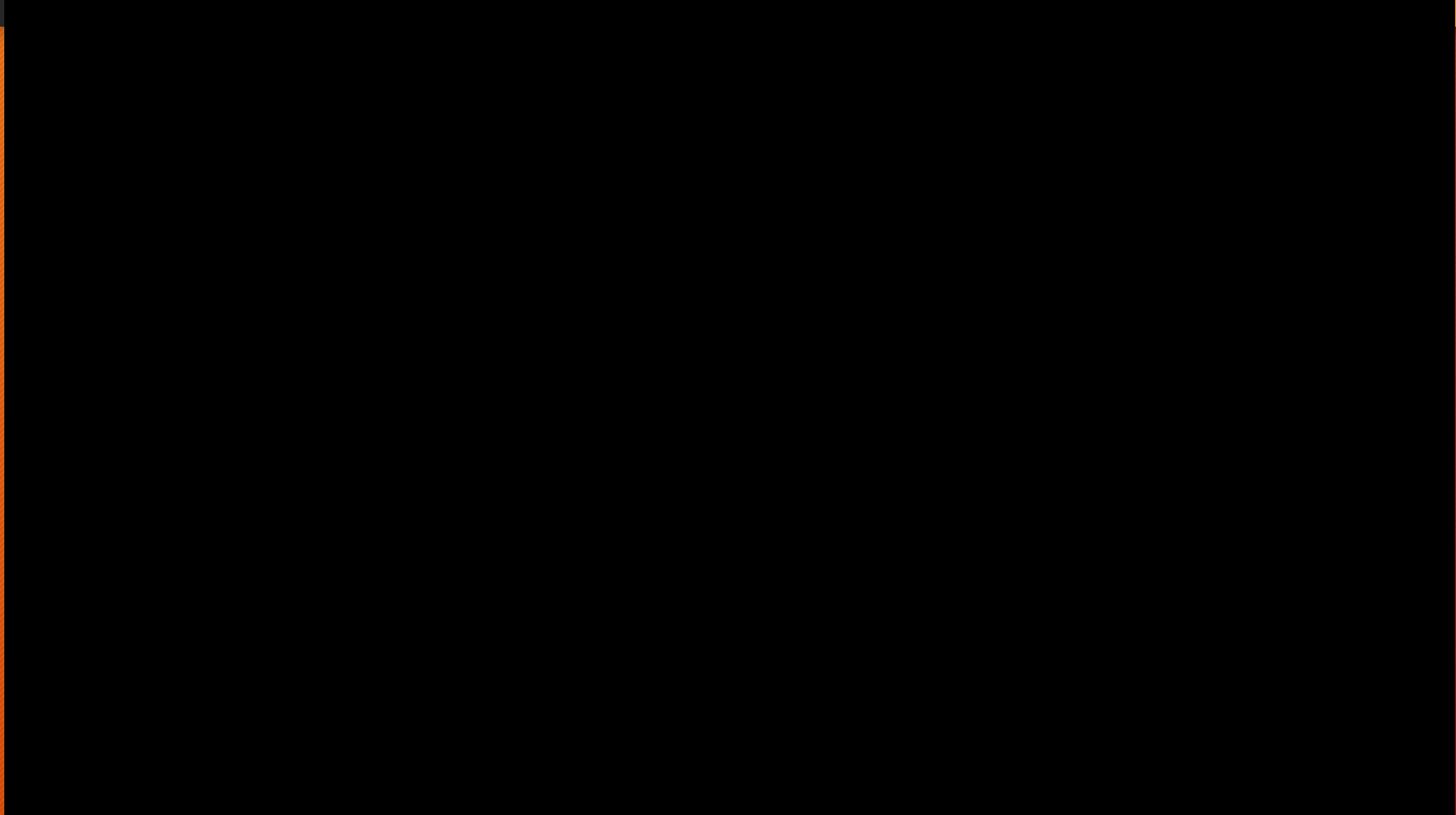


*Click below to play on-line video*

# Ascent Engines Also Kick Up Dust

Morpheus Free Flight #7, NASA Kennedy Space Center

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# Key Take Aways

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- ❑ Robotic missions have provided valuable insights into Martian dust storms
- ❑ Dust storms pose challenges for a human Mars mission
- ❑ NASA is actively considering ways to reduce the impact of dust storms
  - Robust equipment designs
  - Contingency operations planning





# Questions?

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# References

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